U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-260 143

POLLUTION RESEARCH TO PROTECT AQUATIC LIFE

ROBERT A. TAFT SANITARY ENGINEERING CENTER
CINCINNATI, OHIO

1960

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No. PB-260 143
4. Title and Subtitle Pollution Research to Protect Aquatic Life			5. Report Date 1960 6.
7. Author(s) Clarence M. Tarzwell			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstracts

The need for a greatly expanded research program for determining the environmental requirements of aquatic life and for development of adequate water quality criteria for its protection is stated. Water quality criteria will be valuable in the prevention and abatement of pollution, defining the objectives for abatement and waste treatment, informing the public and making it an effective force for abatement, providing a basis for uniform regulation, enabling industry to develop a rational waste control program, and assisting in the development and enforcement of legislation.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms

*Water pollution standards
*Aquatic life
Project planning
Water pollution control
Water quality
Environment management

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 25
	20. Security Class (This Page UNCLASSIFIED	22. Price

PB 260 143

002104 253028

POLLUTION RESEARCH TO PROTECT AQUATIC LIFE

Clarence M. Tarzwell

U. S. Department of Health, Education, and Welfare

Public Health Service

Robert A. Taft Sanitary Engineering Center

Cincinnati, Ohio

The Problem

Water is essential for all life. All living things, plant or animal, are composed mainly of water and constantly require water in their life processes. Water is the most extensive habitat on earth and supports the great assemblage of aquatic life upon which, in the future, we may have to depend more and more for food.

Where good fresh water has been abundant we have often failed to realize its vital importance. We have taken water for granted, wasted it, and used it as a receiver of our wastes. To the early settlers and pioneers America's water supplies appeared inexhaustible. It was only natural for them to use streams to carry away all types of wastes -- even though these streams often furnished their drinking water and an important part of their food.

As population, agriculture, and industry increased, many streams became overloaded with wastes. Some became so bad they ceased to produce fish and became open sewers unsuited for any use other than carrying away wastes. This reduction in water resources did not at first cause any alarm; many felt we had an abundance of streams and could afford to use some for waste disposal.

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

Within recent years, however, it has been realized that even areas plentifully supplied with water cannot continue to dump untreated wastes into the same stream from which domestic water supplies are drawn. Even without such contamination we cannot expect to support indefinitely a population expanding in geometric progression. There is now general agreement that we must use our supplies wisely if they are to serve the needs of all people now and in the future. It is also agreed that since our supplies cannot be significantly increased by any known feasible methods, the best alternative is reuse of water. Water pollution is the outstanding deterrent to water reuse since many wastes make reuse of water difficult or impossible. Pollution control for the maintenance of desired water quality is essential if water resources are to meet future needs.

The President's Water Pollution Control Advisory Board, in its February 3, 1961, report to the Surgeon General of the U. S. Public Health Service, pointed out that, "From now on water quantity requirements can be met only if dependable stream flows can be used over and over. This can be done only if water quality is maintained. To accomplish this, pollution control programs must be given the highest priority in water resources developments." The need for reuse of water is also brought out in the Report of the Committee on Public Works, House of Representatives, in House Report No. 306, 87th Congtess, 1st Session.

The effective reuse of water requires that those who take water from a stream or other source must return that water to its source in such condition that it is suitable for other desired uses. Before this can be done we must know the quality of water required for each of the desired

uses. When these data become available, they will define quality criteria for each of the uses of water, the objectives to be attained in order to prevent or abate pollution, and the level of waste treatment required to meet specific needs. Water quality criteria are the keys to effective reuse of our waters and the economic solution of our water resources problems.

The need for water quality criteria for aquatic life, both marine and freshwater, is especially critical. The quality of water essential for the survival, growth, reproduction, and general well-being of aquatic life must be known if we are to protect, restore, and maintain fishes and other aquatic species of recreational and commercial importance. We must know the environmental requirements of the principal aquatic species before we can have appropriate water quality criteria for their protection.

In seeking to establish these essential criteria, our real problem is a lack of knowledge. There is a need to determine objectives. We need answers to many questions. What concentrations of waste are safe for aquatic life? What levels of treatment should be required in pollution abatement? What are the acute toxicity levels of materials and what concentrations are safe under conditions of continuous exposure? What are the effects of temperature, CO_2, pH, toxic materials, and other environmental factors on oxygen requirements, and what in turn are the effects of DO levels on them? What are the effects of various combinations of environmental factors on the toxicity of various wastes?

We cannot answer these questions without an adequate program of research. The lack of an adequate research program is seriously hindering the development of an effective pollution abatement program.

These problems of water quality have been the subject of limited studies by the nation's aquatic biologists in federal and state agencies and universities. Although progress has been made and some tentative criteria have been developed, (1) (2) (3) (4) (5) (6) (7) (8), the rate of advance has been too slow to match the growing problem. Resources devoted to research in this field have been too small and the facilities inadequate to provide even the answers already needed for water quality management, to say nothing of future demands for facts.

A greatly expanded research program is essential to meet present and future problems. The task of determining the environmental requirements of aquatic life and safe loadings for the host of materials now dumped into our waters will require much effort. New and expanding industries are adding increasing quantities of toxic and persistent wastes that will create more problems. While attempting to catch up on the backlog, we must keep abreast of these problems or slip farther behind than ever.

There are parallels in the history of American research. Those who are acquainted with agricultural developments know the tremendous amounts of effort and study that have been necessary to place American agriculture on its present high level. Through similar efforts but on a smaller scale, we must acquire the knowledge essential to measure

and evaluate pollution, and secure the knowledge necessary to design corrective measures and to develop water quality criteria. Such studies are amply justified by the value of the resource they are to protect or restore. Our commercial fisheries now have an annual yield of about five billion pounds of a high-protein, high-mineral, low-fat food so much needed in our diet today. Commercial fishing is an important industry of value to our continued survival. Important as this resource may be, our sport fisheries are an even more valuable resource having an annual value of about three billion dollars. Clean waters are also health and aesthetic assets and are the bases of much outdoor recreation other than fishing.

Public Support for Expanded Research

The value and the need for setting up water quality criteria for protection of the nation's aquatic life have been recognized generally by conservationists, sportsmen, commercial fishermen and those in the water pollution control field. The Congress and private organizations such as the Sport Fishing Institute, the Izaak Walton League, the Pennsylvania Federation of Sportsmen's Clubs, and others, have publicly resolved that these needs must be met. Only an adequate research program will fulfill these resolves and enable us to meet the problems and attain the desired objectives.

Research Objectives

The ultimate objective of research in this field is the maintenance or restoration of our aquatic life and recreational resources; in short, the prevention or abatement of pollution. This objective may be attained through development and application of water quality criteria

that define the environmental conditions essential for the survival, growth, reproduction, and general well-being of the aquatic biota. These criteria must be based on a detailed and accurate knowledge of the environmental requirements of the organisms to be protected and those which serve as their food.

The immediate objectives of a research program directed toward the solution of the over-all problem are to evaluate the effects of changing those environmental conditions which are required for the general well-being and to determine concentrations of dissolved materials, solids, liquids, and gases, that are essential for optimum conditions; concentrations that are not lethal or detrimental to various developmental stages during short or intermittent periods of exposure; concentrations that can be resisted for extended periods and those which are not harmful or are essential for the continued survival of the biota and the production of an adequate crop under conditions of long-term or continuous exposure. As these immediate objectives are attained, it will be possible to define the goals for a pollution prevention and abatement program. Clear-cut objectives are basic to an effective and efficient pollution control program, since they are essential for the detection, measurement, and evaluation of environmental changes due to waste discharge and are necessary for determining the need, type, and extent of waste treatment.

Research Programs

In the implementation of research programs the usual first step is a review of all pertinent literature. Data secured are then assembled, analyzed, and interpreted so that present knowledge can be evaluated,

the need for additional data determined, and necessary research programmed and planned. Since the number of water pollutants is great and the number of new processes and waste materials is increasing yearly, research should be planned so that each project will answer as many questions as possible. For example, pollutants should be classified not only according to their origin and chemical relationships but also according to their effects on the biota of receiving waters. Such a classification, proposed in 1952, (9) lists five main categories of wastes: inert, inorganic and organic materials, putrescible wastes, toxic wastes, wastes with a significant heat content, and radioactive wastes. A sixth category, tainting substances, has been added to these.

These groups of materials or wastes can serve as a basis for a research program to determine the effects of various pollutants on aquatic environments and their biota.

Determinations should be made of the effects of each of these types of wastes on all important freshwater, marine, and estuarine organisms. These studies should include, but not necessarily be limited to, determinations of concentrations of wastes that are rapidly lethal, maximum amounts that can be tolerated for short or extended periods, and amounts that are safe for all stages of the life history and survival of the species under conditions of continuous exposure. In addition, investigations should be made of the effects of variations in environmental factors, such as temperature, CO_2, DO, pH, alkalinity, and hardness on the toxicity of various wastes. In turn, studies should be made of the influence of these wastes on the environmental

factors listed above and of the physiological, histological, and histochemical effects of sublethal concentrations of these materials on reproduction, activity, and other important life processes throughout the developmental stages of the aquatic organisms. Such research will provide data essential for the formulation of water quality criteria for the protection of aquatic life resources.

Oxygen-depleting or putrescible wastes.

There have been many laboratory studies of the dissolved oxygen requirements of fishes. Most of these studies have been short-term static tests designed to determine the minimum dissolved oxygen concentrations needed for short periods. Little work has been done to determine the long-term needs of the organisms. Many of these studies have not provided the needed information because: (1) species more resistant than those to be protected were tested at low temperatures and under conditions of inactivity, (2) tests usually were of so few hours duration that the fish were not fed and did not carry out normal activities , or (3) evaluation was based on survival without regard to condition of the fish at the end of the test. Such tests do not indicate actual oxygen requirements for normal existence and are no measure of the oxygen required for species survival.

Long-term studies of aquatic life under conditions similar to those found in nature are required for the establishment of dissolved oxygen criteria for freshwater, marine, and estuarine organisms.

Research objectives must include determination of:

1. Minimum dissolved oxygen levels at which important sport and commercial fishes can survive for eight hours under maximum allowable temperatures.
2. Daily minimum dissolved oxygen levels at which important shellfish and sport and commercial fishes and their food organisms can survive for extended periods, under the most critical diurnal variations in dissolved oxygen, CO_2, pH, and temperature, without significant harm to overall productivity.
3. Effects of sublethal concentrations of selected toxic materials on dissolved oxygen requirements for all developmental stages.
4. Dissolved oxygen levels, which in terms of multiple environmental influences, are conducive to survival, growth, reproduction, and general well-being over extended periods for selected fishes, arthropods, mollusks, and important organisms in the food chain. This research may be done on artificially established communities of freshwater, estuarine, and marine biota.
5. The relationship of laboratory findings to field conditions and the testing of proposed criteria under field conditions to determine their adequacy.

Toxic wastes.

Sizable kills of fishes by spills or slugs of toxic wastes are publicized and condemned. Such kills, even though important and spectacular, may not be as disastrous as the insidious slow destruction of aquatic populations due to the continuous addition of low concentrations

of toxicants, for example, acid mine wastes. When considering water quality criteria for the protection of aquatic life, it is necessary to determine the toxic waste concentrations that kill only after extended periods of exposure or subtly reduce the general well-being and productivity without destroying the entire population.

The research program should include studies to determine concentrations of toxicants that can be tolerated indefinitely by the aquatic biota. When these concentrations are known for those wastes or materials whose toxicity is significantly influenced by the quality of the receiving water, it may be possible to develop application factors that can be used with the results of short-term bioassays to indicate safe concentrations of these wastes in a particular water. The short-term bioassay is suggested because it gives an evaluation of the effects of water quality on the toxicity of the waste and it can be performed by various agencies and industries not equipped for more extensive bio-evaluations.

Toxicity studies should include the following:

1. Exploratory and short-term tests to determine the acute toxicity of various wastes and chemicals to fishes and other aquatic organisms in freshwater, marine, and estuarine environments.
2. Development and evaluation of tests for the determination of long-term toxicity to important groups of freshwater and marine organisms.

3. Long-term tests under constant-flow conditions that simulate the environmental extremes that actually occur in nature and those proposed in suggested water quality criteria. In these tests the main groups of organisms in the aquatic biota should be exposed to complex wastes and chemicals to determine cumulative effects on reproductive cells and early stages of the life cycles, on different species within the groups and different genetic groups, and on different size groups during the different seasons. Effort should be made to determine maximum concentrations that do not seriously affect survival, growth, reproduction, general well-being, and productivity of aquatic communities.

From such research data, criteria may be established for materials whose toxicity is not influenced significantly by variations in the quality of the receiving water. For materials, whose toxicity is altered by the character of the receiving water, application factors should be developed to permit the use of results of short-term bioassays to estimate safe concentrations in the receiving water for the particular waste and area affected. Efforts should be made to develop techniques that readily facilitate industrial application of procedures required for the achievement and maintenance of acceptable water quality. There is also a need for chemical analytical methods suitable for application to toxicity problems. Tests are needed to determine whether wastes or chemicals are present in forms that are toxic to aquatic life.

For example, sensitive analytical methods for the determination of cyanide in polluted waters have been developed but no distinction has been made between free molecular hydrocyanic acid and complex metallo-cyanide ions. Recent studies have indicated that it is the HCN molecule that is toxic.

At present, the causes of fish kills usually cannot be determined by examining the dead fish, nor can such kills often be traced to any specific source of pollution. Little is known concerning the physiological or pathological changes in fish caused by toxic substances. There is great need for development of methods to determine the cause of fish kills by examination of the affected or recently killed fish. These studies should include:

1. Investigation of histological, histochemical, chemical, and other methods for detecting specific changes in or damage to specific tissues of fish and other aquatic organisms exposed to different concentrations of toxicant. When applicable, radioactive tracers may be used to determine the tissues in which toxic materials concentrate when aquatic populations are exposed to a range of concentrations of a particular toxicant.
2. Physiological examinations and tests to determine damage to an organism, as related to observed changes in tissues.
3. Analysis and correlation of these findings with the aim of developing more specific methods than are now available for determining the cause of kills.

Contaminants

In the establishment of criteria intended to prevent the tainting of fish flesh, the practical problem is to determine the maximum concentrations of potential tainting materials that may be permitted in water without affecting fish flavor. This research should include:

1. Development of efficient and reliable methods for evaluating the effects of tainting materials on the flavor of important food fish species.
2. Tests with these methods to determine the maximum concentrations of tainting materials allowable, singly or in combinations, without causing off-flavor or odors in the flesh.

Inert inorganic and organic materials.

Materials eroded from the land are universal pollutants and perhaps the most important. Wastes from placer, hydraulic, coal, ore, and other mining, and from washing, mixing, sifting, scrubbing, and other industrial operations likewise cause unfavorable conditions in our waters. Silt and other settleable solids cover spawning areas, reduce the production of bottom organisms in gravel bottom streams, fill pools, destroy cover, choke streams, and fill ponds, lakes, and reservoirs. Turbidity due to settleable and suspended materials may limit light penetration and inhibit the photosynthetic activity of algae. In turn, the decreased productivity of aquatic plants may adversely affect the whole food chain. Muddy waters are less favorable for game fish, which feed by sight, than for coarse species that do not feed this way, and thus may be

responsible for undesirable changes in fish populations.

Water quality criteria for inert turbidity and settleable solids would vary with the section of the country and type of stream. In the Great Plains area streams are of such character that a little more silt would have negligible effect, whereas in glaciated areas having clear, gravel-rubble-bottom streams, any appreciable addition of settleable solids adversely affects the production of important bottom organisms. Research on this program should include:

1. A study to determine the amount of light required for the growth of plankton and rooted aquatic plants and for the production of oxygen in excess of that used in plant respiration. This study would include determination of incident light and the percentage of it reaching certain depths in various waters under a variety of conditions.
2. Studies to determine direct and indirect effects of settleable solids of different types and turbidity on the aquatic biota, including direct harmful effects on gill and other tissues, and effects on spawning, food production, feeding, competition of different species, reproduction, and productivity.

Wastes with significant heat content.

The increase in the demand for electrical power and the expansion of industries requiring cooling waters result in the addition of ever-increasing amounts of heat to our waters. In some areas the added heat has exceeded the acceptance capacity of the streams and water temperatures have reached levels unfavorable for aquatic life.

Much must be learned before temperature criteria for the protection of all members of the aquatic biota can be established. Research is needed to:

1. Determine maximum temperatures that can be tolerated for intermittent short periods by the aquatic biota and the effects of sudden temperature changes on the biota.
2. Determine maximum diurnal water temperature variations that can be tolerated for long periods. Concurrent maximum or minimum levels of other factors in the environment, such as dissolved oxygen, CO_2, and pH, should be varied in accordance with typical diurnal variations to determine the total environmental effect. Changes in temperature should be made slowly in order that the effects of acclimation can be determined.
3. Determine temperatures that are avoided by the principal species of the major groups of organisms; i. e., the temperature levels at which thermal blocks exist.
4. Utilize aquatic communities, typical of cold and warm fresh, marine, and estuarine waters, in long-term studies to determine temperature effects on survival, growth, reproduction, competition, predation, parasitism, disease, and general well-being.

Radioactive wastes.

It is expected that radioactive wastes will become a more important problem as the number of atomic power stations increases and radioactive materials are more widely used in industry. Because certain members of the biota concentrate these materials to levels many times those in the water, radioactive materials may prove useful as monitoring tools. Radioactive materials may also be used as reaearch tools in tracing toxicants to their sites of buildup in the body, in measuring their stability in the environment, and in finding the amount of radioactivity to which the organisms are exposed. If preliminary examination indicates a need, studies should be made of the buildup of radionuclides in the flesh of food animals, the passage of radionuclides through the food chain, and their direct harmful effects to the biota.

Research Benefits

Data acquired by a research program for the determination of the environmental requirements of important organisms in the fresh water, marine, and estuarine biota provide the basis for the formulation of water quality criteria for aquatic life and thus are of great value in the meeting of water pollution problems. Such criteria would have a number of uses and values.

1. They would define the water quality characteristics essential for the survival, reproduction, and well-being of the aquatic biota; that is, the environmental conditions that must be maintained for the production of a suitable crop. Without such criteria pollution cannot be efficiently detected or effectively controlled because the water quality requirements that must be met are unknown or undefined.

The objective to be attained; namely, satisfactory environmental conditions, is not known. With such a lack of knowledge of direction and objectives, abatement attempts must of necessity be hit or miss and uncoordinated.

2. They would define effluent criteria and the waste treatment goals that must be attained for the prevention of pollution and the maintenance of desirable environmental conditions in receiving waters.
3. They would provide the general public with definite information on what constitutes pollution and safe levels of specific wastes in receiving waters so that public opinion may be an intelligent and effective force for the prevention and abatement of pollution.
4. They would indicate to industry allowable levels of their wastes in selected waters and the kind and amount of waste treatment needed to prevent pollution. This would enable industry to evaluate proposed plant sites in relation to waste disposal, to plan waste treatment facilities efficiently, and to construct treatment facilities at the time new plants are built.
5. Adequate well-documented criteria would lead to more uniform regulations and would prevent industrial developers from securing concessions in waste treatment at the expense of water resources.
6. Well-documented water quality criteria would define water pollution in specific terms and would be of great value in the formulation and enforcement of water pollution laws and in the prevention and abatement of pollution through court action.

Research Facilities and Personnel

Research programs for securing data essential for the formulation of water quality criteria for the protection of aquatic life would, of necessity, be large and long-term projects. Since little is known of the long-term toxicity of existing waste materials, there is a great backlog of work to be done. There is immediate need for a large program and adequate facilities for research to determine the effects of these materials on aquatic organisms and their environment. Further, these must be continuing programs because new and more toxic wastes are being produced at an ever-increasing rate. Adequate facilities, equipment, space, and funds must be available to insure success in these undertakings.

A water supply of suitable quality and quantity must be the first consideration in the selection of sites for research of this nature. Because water supply is the key factor in the selection of a site, great care must be exercised to choose one which is free of all man-made wastes and which will remain free from wastes in the foreseeable future, unthreatened by contamination from expanding population or industry.

For the fresh water studies an ideal site is one where a soft water stream and a hard water spring having adequate and dependable flows are in close proximity, and where space is sufficient for all facilities and where the slope is such that these facilities can be supplied by gravity flow. In order to insure purity of the water supply for the future, the watershed of the stream above the facility should be in a wilderness area or in a national or state park or forest

so that it is protected from human habitation and industrial use. Considerable land should be available for rearing, holding and experimental ponds, storage reservoirs, raceways, and experimental facilities.

The facilities for research on marine and estuarial organisms should be located in areas free of municipal, industrial, and other wastes, preferably in or bordering an extensive waterfowl refuge or other preserve so that the supply of sea water can be kept uncontaminated for the foreseeable future. A protected fresh water supply of the required quality and of adequate and dependable flow is also required for the dilution of sea water to simulate estuarial conditions and to supply other needs of the station. The sea water should have a salinity at all times characteristic of that of open ocean water. Such water can be diluted to represent estuarial water, but there are no practical methods of increasing salinity of the large volumes that would be required. Adequate and desirable space should be available for buildings, holding, rearing and experimental ponds, and protected docking facilities.

A prime requisite for a research program of this nature is an adequate staff of competent, energetic, and dedicated individuals having diversified training and experience in the broad fields of aquatic biology, limnology, biochemistry, physiology, toxicology, pathology, biological oceanography, entomology, ichthyology, and related fields. They must devise equipment and develop methods for solving the many different problems that arise in connection with

the keeping of experimental animals, carrying out short-term and long-term tests, maintaining constant-flow systems, controlling environmental conditions, and setting up multivariate experiments. They must also develop methods for determining and evaluating the sublethal effects over long periods, of various wastes and materials on a great variety of organisms at different stages in their life histories and under a variety of varying environmental conditions. Further, they must evaluate the significance of physiological, histological, and other changes in these organisms, in terms of actual damage to the resource. An outstandingly difficult task will be that of deciding just how much activity, growth, reproduction, and productivity can be decreased, before it is considered that a beneficial use is damaging and that pollution exists.

Summary and Conclusions

Our water resources often have been poorly managed in the past, but it is now recognized that they must be wisely managed in the future if they are to provide all the needs of an expanding population. Since water pollution is a chief cause of the deterioration of most of our waters, pollution control must be given the highest priority in water resource development. Clear-cut, well-defined objectives are basic to pollution abatement programs. Water quality criteria are the keys to effective reuse of our waters and the economic solution of our water resources problems. The need for water quality criteria for aquatic life, both marine and fresh-water, is especially critical. We must know the environmental requirements of aquatic

life before we can develop adequate water quality criteria for their protection. A greatly expanded and continuing research program is essential to meet present and future problems. Conservation groups have recognized the need for such a program that would have as its ultimate objective the maintenance or restoration of our aquatic life and recreational resources. The immediate objectives of a research program for the establishment of water quality criteria is the determination of environmental conditions that are essential for the general well-being, the production of a crop, and the determination of waste concentrations that are not harmful to the aquatic biota. The collection of data needed for the formulation of water quality criteria requires a large and continuing program by federal and state governments, research institutes, agriculture, industry, and educational institutions. The prime requisite in the setting up of laboratories and facilities for carrying on these research programs is a water supply of adequate quantity and quality. Space is also required for holding, rearing, and experimental facilities. A well-trained and experienced staff is a basic essential for such programs.

When formulated, tested, and documented, water quality criteria will be of great value in the prevention and abatement of pollution. They will define the objectives to be attained for pollution abatement or prevention and for waste treatment; inform the public of what must be done for the prevention of pollution and thus make public opinion an effective force for pollution abatement; provide the basis for

uniform regulations; inform industry of the requirements to be met, enabling them to develop a rational waste control program; and assist in the development and enforcement of water pollution legislation.

References

1. Tarzwell, Clarence M., Water Quality Criteria for Aquatic Life. Trans. Seminar on Biological Problems in Water Pollution, held in Cincinnati, Ohio, April 23-27, 1956. pp 246-272 (1957).
2. Aquatic Life Advisory Committee/Ohio River Valley Water Sanitation Commission, Aquatic Life Water Quality Criteria. First Progress Report. Sew. and Ind. Wastes, 27, 3, 321-331 (March 1955).
3. Aquatic Life Advisory Committee/Ohio River Valley Water Sanitation Commission, Aquatic Life Water Quality Criteria. Second Progress Report. Sew. and Ind. Wastes, 28, 5, 678-690 (May 1956).
4. Aquatic Life Advisory Committee/Ohio River Valley Water Sanitation Commission, Aquatic Life Water Quality Criteria. Third Progress Report. Jour. Water Poll. Control Fed., 32, 1, 65-82 (Jan. 1960).
5. Ellis, M. M., Water Purity Standards for Fresh Water Fishes. U. S. Fish and Wildlife Service. Spec. Sci. Rep. No. 2. Mimeo. pp 1-15 (1944).
6. Ellis, M. M., The Detection and Measurement of Stream Pollution. Bull. Bur. Fish., 48, 22, 365-437 (1937).
7. Calif. Water Poll. Control Board, Water Quality Criteria. State Water Poll. Control Board Pub. No. 3, pp 1-512 (1952).

8. Calif. Water Poll. Control Board, Water Quality Criteria. Adden. No. 1, State Water Poll. Control Board Pub. No. 3, Addendum No. 1, pp 1-164 (1954).

9. Tarzwell, C. M. and Peter Doudoroff. Application of Biological Research in the Control of Industrial Wastes. Proc. of the Natl. Tech. Task Comm. on Industrial Wastes held in Cincinnati, Ohio, June 3-4, 1952. (1952).